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PROVISIONAL SPECIFICATION

PANEL ANTENNA HAVING ADJUSTABLE DOWN TILT

We, **DELTEC NEW ZEALAND LIMITED** a New Zealand company of 84 Main Road, Tawa, Wellington, New Zealand, do hereby declare this invention to be described in the following statement:

The present invention relates to a panel antenna. More particularly, but not exclusively, the present invention relates to a panel antenna having both mechanical and electrical means for tilting the beam of the antenna. The antenna of the present invention is considered to be particularly suitable for use in cellular communication systems.

To the present time most panel antennas used in cellular communication systems have been adjusted by purely mechanical means. Where the antenna are to be affixed to the sides of buildings it is preferable that the panels conform as closely as possible with the sides of the buildings for aesthetic reasons and to avoid exposing too great a surface area to the wind. Where a purely mechanical down tilt is used a panel may be tilted by as much as 15° with respect to a building, which is unsightly, poses mounting difficulties and exposes the panel to the full impact of the wind.

Another method of downwardly tilting the beam of a panel antenna is to electronically phase shift the signal received by or transmitted by each radiating element an amount corresponding with the desired degree of beam tilt. As the amount of downward tilt required for each site varies this would require the use of variable phase shifting elements and would be expensive.

It is an object of the present invention to provide a panel antenna allowing customer adjustable beam down tilt which is relatively cheap and simple whilst being easily mounted and aesthetically pleasing, or to at least provide the public with a useful choice.

Further aspects of this invention will become apparent from the following description.

According to the invention there is provided a panel antenna having a plurality of radiating elements wherein the length of the feed line to a first group of said radiating elements may be adjusted to tilt the beam of the panel antenna.

The panel antenna may also be provided with mechanical tilting means to tilt the panel antenna.

Further aspects of this invention, which should be considered in all its novel aspects, will become apparent from the following description given by way of example of possible embodiments thereof and in which references made to the accompanying drawings wherein;

Figure 1: shows the dipole pairs of a panel antenna mounted on a panel.

Figure 2: shows one of the radiating elements in detail.

<u>Figure 3</u>:	shows in detail the connection of the feed line to the radiating element shown in figure 2.
<u>Figure 4a</u>	shows the radiation patterns for 0°, 5° and 10° of down tilt
<u>Figures 4 and 5</u>:	show electrical diagrams of the possible radiating element configurations.
<u>Figure 6</u>:	shows a possible housing and tilt mechanism for the panel antenna.
<u>Figure 7</u>:	shows the back panel of the assembly shown in figure 6.
<u>Figure 7a</u>:	shows a cover which may be used to cover the assembly shown in figure 6.
<u>Figure 8</u>:	shows the tilting mechanism of figure 6 in greater detail.
<u>Figure 9</u>:	shows an alternative tilting mechanism.
<u>Figure 10</u>:	shows the tilting mechanism of figure 9 as seen through the aperture in the back panel.

Figure 11: shows an alternative construction of the mechanism shown in figure 9.

Figure 12: shows the central hinge of the mechanism shown in figure 11.

Figures 13 and 14: show a wall mounting bracket for use in securing the panel antenna.

Figure 15: shows a means of attaching the panel antenna to the wall mounting bracket.

The present invention relates to a panel antenna designed to operate over a wide band width (eg: 820 - 960 MHz) with constant beam tilt wherein the angle of beam tilt is adjustable by the customer on site.

Referring now to figure 1 the feed lines and radiating elements of a four dipole pair panel antenna are shown. The four pairs of centre fed dipoles 1, 2, 3 and 4 are mounted to a panel 5 which forms the electrical ground plane. Panel 5 is tray shaped and preferably formed of Aluminium. Preferably panel 5 is about 3.45L high by about 0.95L wide having side walls about 0.315L high (where L is the wavelength at the operating frequency). The dipoles in each pair are arranged in parallel and separated by L/2 so that in conjunction with the ground plane 5 they provide an H field

beam of 60°. The dipole pairs 1, 2, 3 and 4 are preferably formed of brass and insulated from panel 5 by an insulating layer (such as a double sided foam tape) to avoid corrosion.

An RF signal supplied at connector 6 is divided by power divider 7 between lines 8 and 9. Line 9 has a turn 10 which makes this line of greater length than line 8 so that the signal it supplies to power divider 11 is phase delayed with respect to the signal supplied to power divider 12. Likewise line 13 which supplies dipole pair 2 is longer than line 14 supplying dipole pair 1 so that the signal provided to dipole pair 2 is phase delayed with respect to that provided to dipole pair 1. Line 15 is also longer than line 16 so that the signal supplied to dipole pair 4 is phase delayed with respect to that supplied to dipole pair 3.

In this way, from dipole pair 1 to dipole pair 4 the signal received or transmitted by the dipole pair is increasingly phase delayed. This delay produces an apparent down tilting of the beam propagated by the panel antenna.

By altering the length of line 8 the degree of down tilt of the panel antenna can be varied. According to the present invention the length of line 8 may be varied by inserting variable lengths of feed line in line 8. The variable lengths of line may be provided with connectors at either end which plug into connectors on the severed ends of line 8.

Referring now to figure 2 a dipole pair is shown. The outer conductor of feed line 17 is soldered to plate 18 and supplies power to radiating elements 19 and 20. The central conductor of feed line 17 is soldered to plate 21 and feeds radiating elements 22 and 23. The radiating elements 19, 20, 22 and 23 are preferably tapered toward the end attached to plate 18 and 21. Radiating elements 19 and 22 and 20 and 23 have insulating spacers 24 therebetween and may be fixed together by insulated securing means. The spacers 24 are preferably formed of PTFE and the radiating elements are preferably secured by nylon screws. This ensures that the assembly is secure and steady against vibrations which may be caused by wind etc.

Referring now to figure 3 the connection of feed line 17 to the dipole pair is shown in more detail. Outer conductor 25 is soldered to plate 18 and inner conductor 26 is soldered to plate 21. Plates 21 and 27 provide capacitive coupling to match the dipole pair.

Referring now to figures 4 and 5 electrical circuits of possible configurations are shown. The circuit shown in figure 4 uses approximately 35 Ohm quarter wavelength power dividers 28 throughout. Accordingly, each radiating element 1, 2, 3 and 4 receives the same power although the signal is phase delayed from dipole pair 1 to dipole pair 4. The phase delays 30, 31 and 32 are fixed and will normally merely consist of a length of feed line. Preferably delay 31 is the same as delay 32 and is selected to give the best side lobe

pattern. Phase delay 29 is variable and in the preferred embodiment of this invention tilting of the antenna beam is achieved by varying the length of cable between connectors 29a and 29b. It is the ratio of the delays 29 to 30 which provides most of the main lobe down tilt. Accordingly, the desired amount of down tilt can be obtained by a customer merely by selecting the required length of cable 29.

Where the panel antenna is to be used in cellular communication systems it should have little radiated power at angles above the main lobe extending to approximately 10° above the horizon. As frequencies may be reused outside a given cell this minimises interference in communications systems.

In an array with constant element separation d, the required degree of down tilt $\ominus$ may be achieved by feeding the elements with a progressive phase shift S given by:

$$S = \frac{360 \times d}{L} \tan \ominus$$

where L is the wavelength at the frequency of operation.

However, with only one phase adjuster and many dipole pairs the phase of signal supplied to each dipole pair cannot be optimum for all angles of down tilt. Thus the radiation pattern must be optimised for a selected angle of down tilt and performance compromised for the other angles.

In one embodiment four dipole pairs were used and the best compromise was achieved for a down tilt of 10°. If d = 0.8L then S = 50.8° (thus elements 31 and 32 in figure 4 are phase delays of 50.8°). The radiation pattern obtained when the phase shift between delay 29 and delay 30 (delay 29 - delay 30) is 0°, 50.80° and 101.6° is shown in figures 4a, 4b and 4c respectively. It is seen in figure 4c that the upper lobes are minimised when the angle of down tilt is 10°.

Referring now to figure 5 this circuit incorporates power dividers 33, 34, 35, 36, 37 and 38. These power dividers may have differing characteristics to give different power division. This may enable better control of the side lobes.

It is to be appreciated that other numbers of radiating elements may be used in other embodiments. Embodiments incorporating 2, 4, 8 or 16 ... radiating elements are particularly preferred.

Referring now to figure 6 the panel shown in figure 1 is seen housed within box 40. Panel 5 is rotatable with respect to box 40, preferably about centre of gravity 41. Box 5 may be pivoted about point 41 by any suitable pivoting means connected to box 40. Box 40 may be mounted to a building or tower etc by means of brackets 42.

By allowing rotation of panel 5 with respect to box 40 a certain degree of mechanical down tilting of the antenna beam may be achieved. In one embodiment, with reference to

figures 7 and 8 as well, an aperture 43 may be provided in the back of box 40 through which a person can grasp handle 44 and by pushing or pulling rotate panel antenna 5 with respect of box 40.

A pair of lugs 45 and 46 are attached to box 40 and panel 5 respectively. Lug 46 has an arcuate grove 47 therein which corresponds with the arc of a circle about point 41. Lug 45 has a grove 48 therein in the vertical direction. A bolt 49 passes through the grooves 47 and 48 so as to restrict rotation of panel antenna 5 with respect to box 40 to the movement allowed between the ends of grove 47.

In use an operator may grab handle 44 and rotate panel antenna 5 with respect to box 40 until bolt 49 is adjacent the required amount of down tilt indicated on indicator 50. When in the correct position the operator will then fasten a nut (not shown) to bolt 49 to secure the assembly firmly in place and prevent further rotation of panel 5. A spirit level 51 may also be provided so that an operator may check to see that the assembly is level when initially installed.

Connectors 29a and 29b may be positioned so as to be easily accessable through aperture 43. In this way lengths of cable may be easily interchanged to give different degrees of down tilt.

Thus, the panel antenna of the present invention provides for a combination of customer adjustable mechanical down tilt and

customer adjustable electrical down tilt (by varying the length of cable 29).

Different lengths of cable 29 may be provided to achieve 0°, 5° and 10° electrical down tilt with 5° of mechanical down tilt being available. In this way steps of 5° electrical down tilt may be provided and fine tuning may be achieved within the range of 5° mechanical down tilt. A total of 15° down tilt may be achieved in this embodiment.

For some applications only electrical down tilt may be required and panel 5 may be directly mounted without the need for box 40 or the mechanical down tilt mechanism. If only electrical down tilt is employed then a greater range of cable lengths 43 may be provided to allow finer control of the amount of down tilt.

According to another embodiment a plurality of switches may be provided on the back of panel 5 which enable the lengths of a plurality of feed lines to be adjusted. If the length of a number of feed lines can be adjusted then a better radiation pattern can be achieved for the non-optimum angles of down tilt. This approach is however more expensive. In another embodiment the feed line lengths may be adjusted remotely using a solenoid rotary switch etc.

Figure 7a shows a cover suitable for covering the whole antenna assembly. This may be formed of rovel (styrene acrylonitrite copolymer) which is a material having low radio frequency loss and high resistance to ultraviolet radiation.

Cover 7a protects the front and sides from the elements with access port 43 being closed by a suitable weather-proof portal cover.

Referring now to figure 9 an alternate mechanism for adjusting mechanical down tilt is shown. A bracket 52 is secured to the back of panel 5 with members 53 and 54 being pivotally connected to each other and box 40 and panel 5 respectively. Adjustment means 55 is connected between the point of connection of members 53 and 54 and bracket 52. The length of adjustment means 55 may be adjusted by rotating turn buckle 56 with respect to threaded shaft 57. As the length of adjustment means 55 is increased members 53 and 54 are straightened which tilts panel 5 further forward with respect to box 40. A lock nut 58 is provided to secure the mechanism when the desired degree of down tilt is achieved. A spring 59 may be connected between bracket 52 and the intersection of members 53 and 54. This spring may be provided with an indicator 60 which moves along a graduated scale 61 to indicate the degree of down tilt (as best seen in figure 10).

This mechanism has the advantage that fine adjustment may easily be made by an operator through port 43 and the operator need have no special tools. Panel 5 will preferably be electrically isolated from box 40 so as to prevent corrosion and members 53 and 54 will preferably be formed of an insulating material.

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The present invention thus provides a cheap and relatively simple panel antenna having customer adjustable electrical and mechanical down tilt which is particularly suitable for application in cellular telephone networks.

Where in the aforegoing description reference has been made to integers having known equivalents then such equivalents are herein incorporated as if individually set forth.

Although this invention has been described by way of example and with reference to possible embodiments thereof it is to be appreciated that improvements and modifications may be made thereto without departing from the scope or spirit of the present invention.

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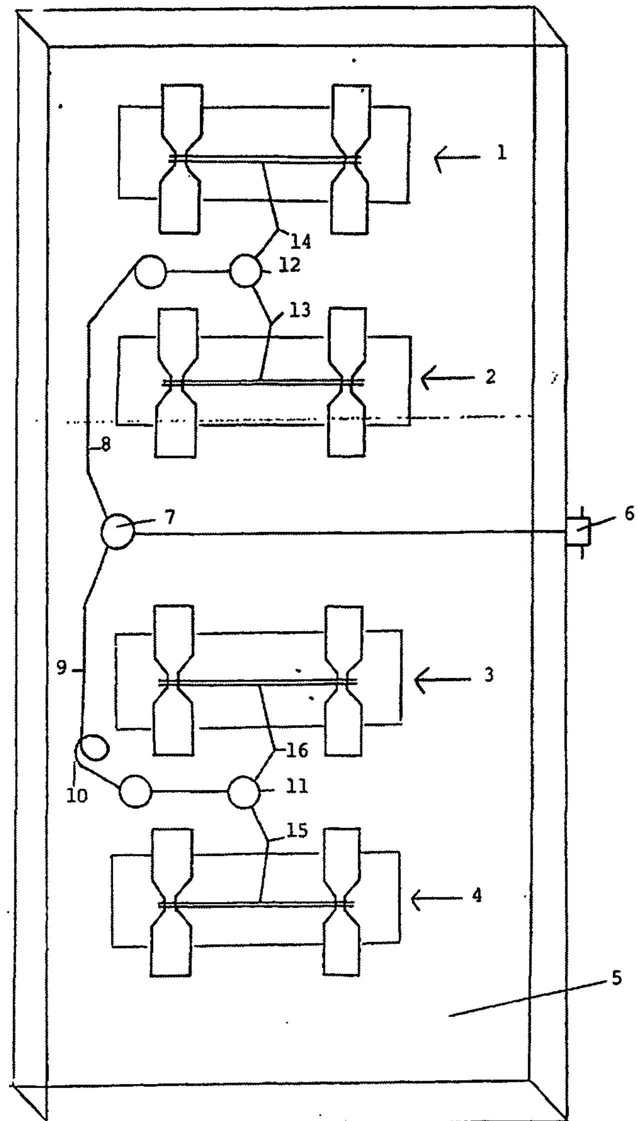

FIG.1

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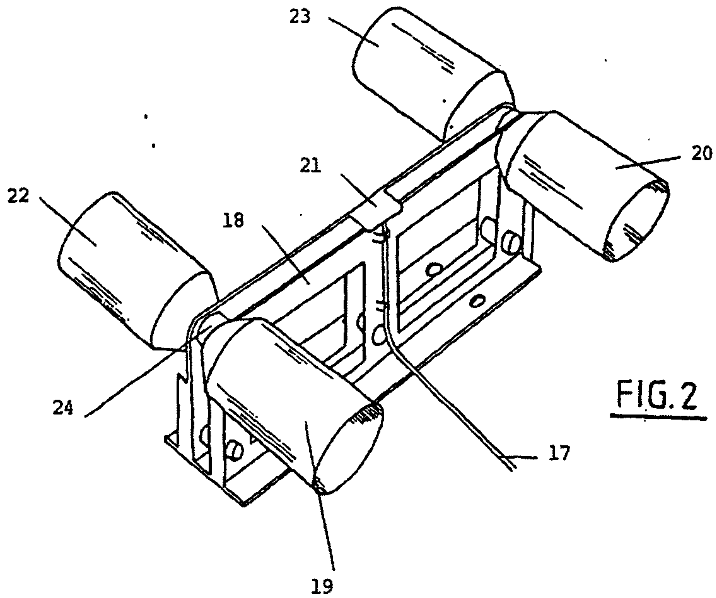

FIG. 2

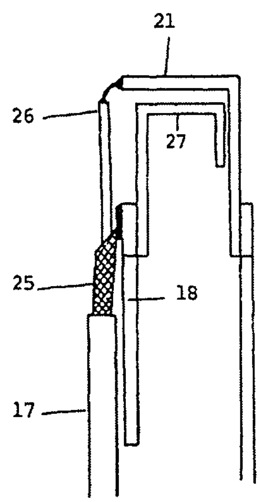

FIG. 3

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Fig 4a

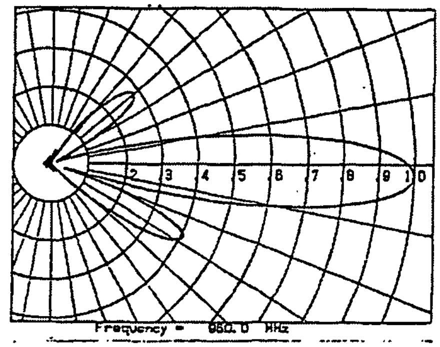


Fig 4b

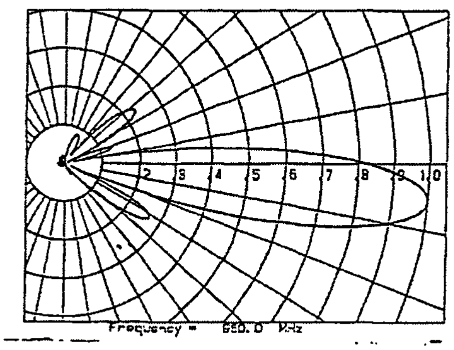
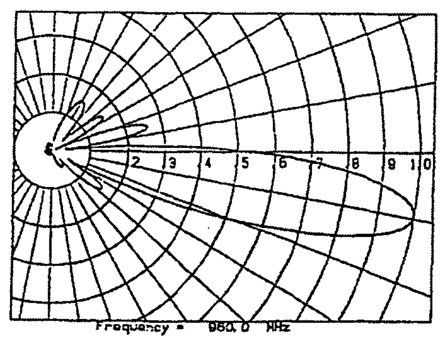


Fig 4c



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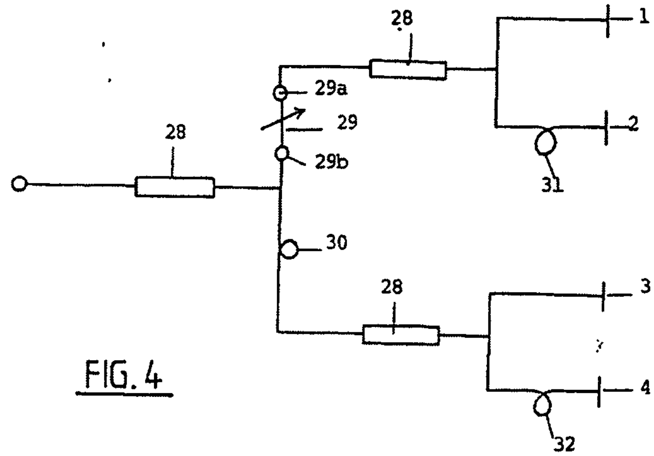

FIG. 4

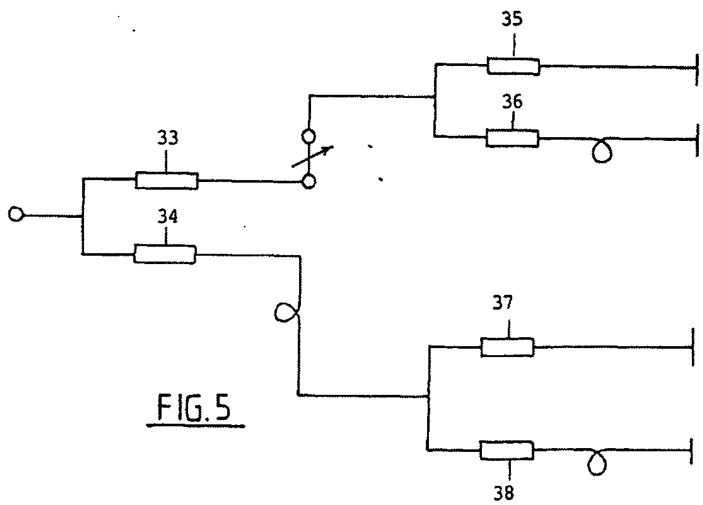

FIG. 5

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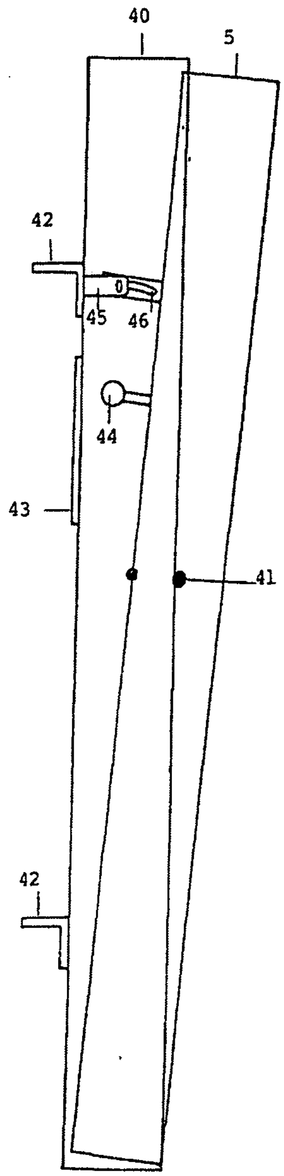

FIG. 6

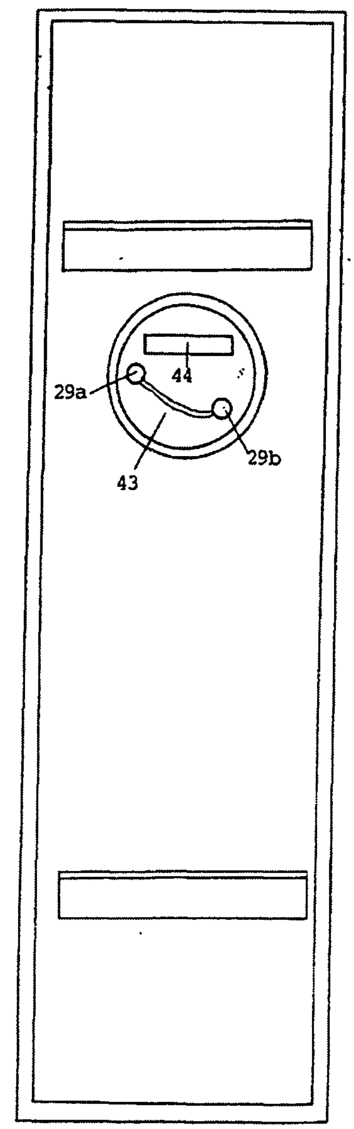

FIG. 7

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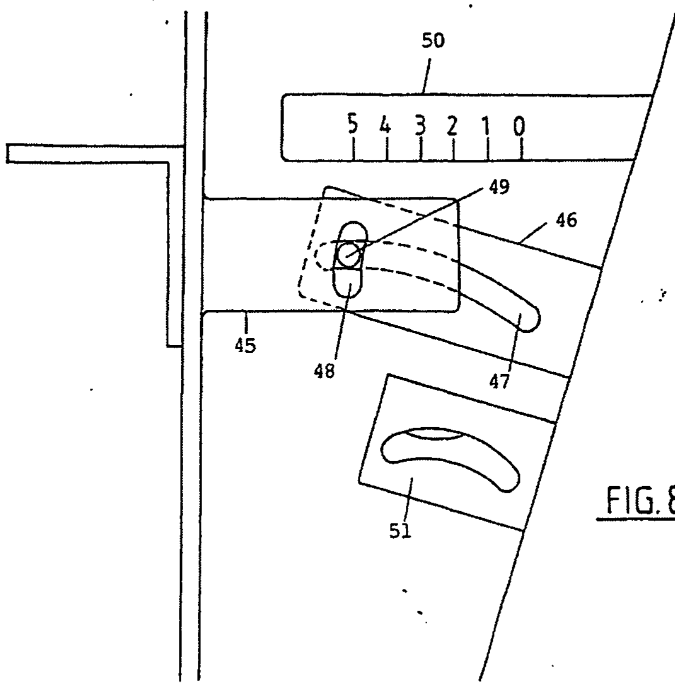

FIG. 8

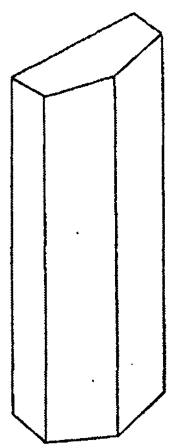

FIG. 7a

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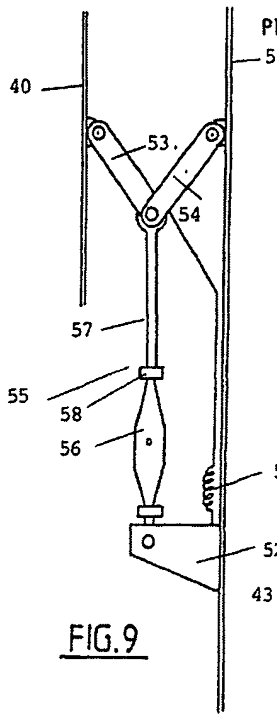

FIG.9

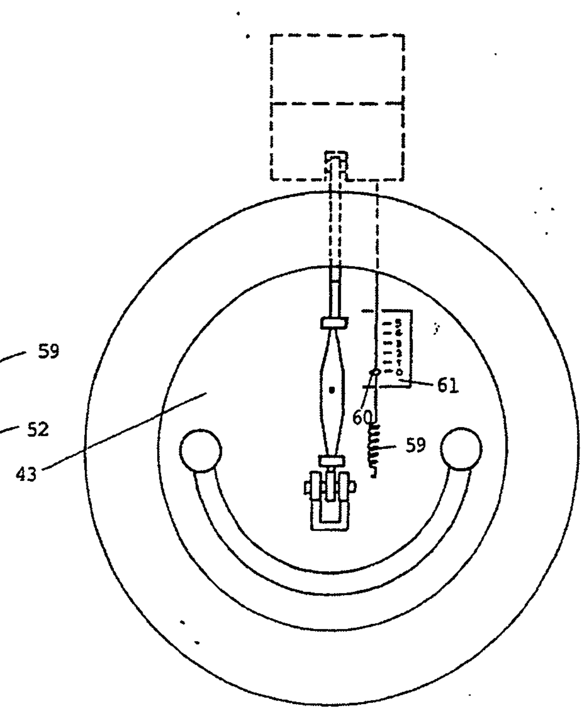

FIG.10

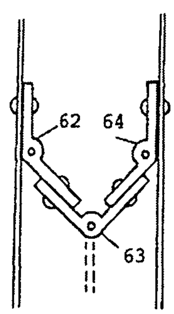

FIG.11

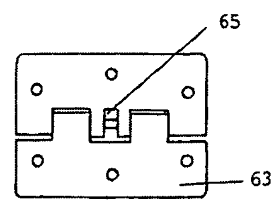

FIG.12

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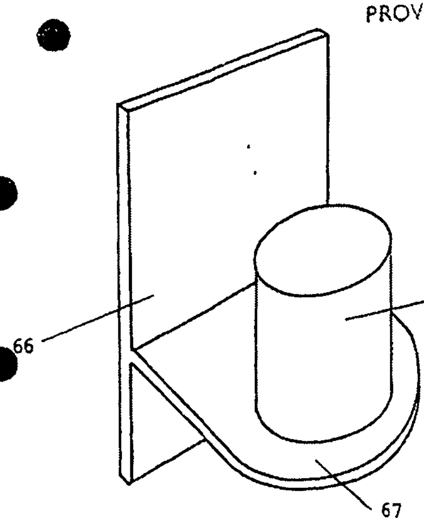

FIG.13

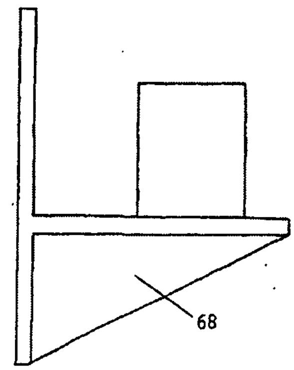

FIG. 14

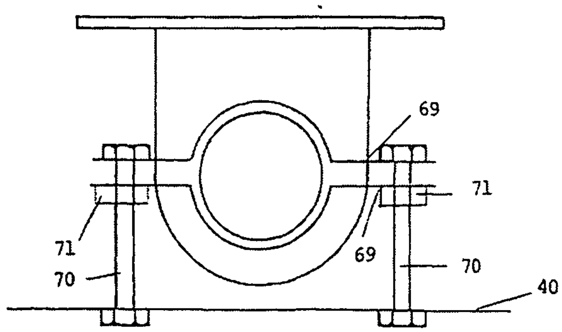

FIG.15

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Patents Form No. 5

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COMPLETE SPECIFICATION

COMPLETE AFTER PROVISIONAL No. 235010

FILED 22 AUGUST 1990

PANEL ANTENNA HAVING ADJUSTABLE DOWN TILT

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WE, **DELTEC NEW ZEALAND LIMITED**, a New Zealand company of 84 Main Road, Tawa, Wellington, New Zealand, hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

signal between first feed line 8 and second feed line 9. Line 9 has a turn 10 which makes this line longer than line 8 so that the signal it supplies to power divider 11 is phase delayed with respect to the signal supplied to power divider 12. Likewise line 13 which supplies dipole pair 2 is longer than line 14 supplying dipole pair 1 so that the signal provided to dipole pair 2 is phase delayed with respect to that provided to dipole pair 1. Line 15 is also longer than line 16 so that the signal supplied to dipole pair 4 is phase delayed with respect to that supplied to dipole pair 3.

In this way, from dipole pair 1 to dipole pair 4 the signal received or transmitted by the dipole pair is increasingly phase delayed. This delay produces an apparent down tilting of the beam propagated by the panel antenna.

By altering the length of line 8 the degree of down tilt of the panel antenna can be varied. According to the present invention the length of line 8 may be varied by inserting variable lengths of feed line in line 8. The variable lengths of line may be provided with connectors at either end which plug into connectors on the severed ends of line 8.

Referring now to figure 2 a dipole pair is shown. The outer conductor of feed line 17 is soldered to plate 18 and

supplies power to dipole elements 19 and 20. The central conductor of feed line 17 is soldered to plate 21 and feeds dipole elements 22 and 23. The dipole elements 19, 20, 22 and 23 are preferably tapered toward the end attached to plate 18 and 21. Dipole elements 19 and 22 and 20 and 23 have insulating spacers 24 therebetween and may be fixed together by insulated securing means. The spacers 24 are preferably formed of PTFE and the dipole elements are preferably secured by nylon screws. This ensures that the assembly is secure and steady against vibrations which may be caused by wind etc.

Referring now to figure 3 the connection of feed line 17 to the dipole pair is shown in more detail. Outer conductor 17 is soldered to plate 18 at formed cleat 25 and inner conductor 26 is soldered to plate 21. Plates 21 and 27 provide capacitive correction to match the dipole pair.

Referring now to figures 4d and 5d electrical circuits of possible configurations are shown. The circuit shown in figure 4d uses approximately 35 Ohm quarter wavelength power dividers 28. A high power matching section 28a is provided to match the antenna impedance to the impedance of cable 6a. Matching section 28a is shown in figure 5a. Flanged end caps 28b formed of PTFE are provided at either end and support an outer conductive tube 28c. A central conductor 28d is supported within the outer conductor by

the caps 28b. A tubular dielectric section 28e formed of PTFE can slide along inner conductor 28d. The resistance R of the matching section is dependant upon the length of the tubular dielectric section 28e (and hence the amount of PTFE).

The reactance can be varied by moving the tubular dielectric section 28e toward one end or the other. Movement of the tubular dielectric section 28e towards the load end will cause the impedence to go inductive whereas movement towards the cable end will cause the impedence to go capacitive. Once the optimum position has been established the tubular dielectric section 28e can be permanently positioned; for example by providing PTFE spaghetti spacers between the tubular dielectric sections and the end caps 28b. Preferably the length of the matching section will be one fifth of the operating wavelength.

Referring back to figure 4d, in this embodiment each radiating element 1, 2, 3 and 4 receives the same power although the signal is phase delayed from radiating element 1 to radiating element 4. The phase delays 30, 31 and 32 are fixed and will normally merely consist of an extra length of feed line. Preferably delay 31 is the same as delay 32 and is selected to give the best sidelobe pattern. Phase delay 29 is variable and in the preferred embodiment of

this invention tilting of the antenna beam is achieved by varying the length of cable between connectors 29a and 29b. It is the ratio of the delays 29 to 30 which provides most of the main lobe down tilt. Accordingly, the desired amount of down tilt can be obtained by a customer merely by selecting the required length of cable 29 from a selection of lengths.

Where the panel antenna is to be used in cellular communication systems it should have little radiated power at angles above the main lobe extending to approximately 10° above the horizon. As frequencies may be reused outside a given cell this minimises interference in communications systems.

In an array with constant element separation d, the required degree of down tilt t may be achieved by feeding the elements with a progressive phase shift S given by:

$$S = \frac{360 \times d}{L} \sin t$$

where L is the wavelength at the frequency of operation.

However, with only one phase adjuster and many radiating elements the phase of signal supplied to each radiating element cannot be optimum for all angles of down tilt.

Referring now to figure 11 an embodiment is shown in which members 53 and 54 shown in figure 9 are formed by three hinges 62, 63 and 64. This configuration has the advantage that the hinges have very little movement about their joints so the assembly will be securely fastened in place. The hinges 62, 63 and 64 will preferably be formed of nylon or plastic material to isolate box 5 from box 4. The hinge 63 shown in figure 12 will preferably have a notch 65 therein to allow attachment of the adjustment means 55.

Referring now to figure 13 a mounting bracket for securing the panel antenna assembly to a wall is shown. The bracket is seen to comprise a back plate 66, a horizontal plate 67, an angle support plate 68 and a cylindrical pin 69. Back plate 68 may be affixed to a wall by any suitable means such as bolting. A panel antenna assembly may be mounted onto two such vertically disposed support brackets using two mounting brackets 69 fastened together by bolts 70 and nuts 71. This assembly has the advantage that the panel antenna assembly is rotatable with respect to the brackets through 40° in either direction. This assists in adjustment of the antenna down tilt after installation as upon loosening of nuts 71 the panel antenna assembly may be rotated to enable access through the rear thereof.

Where the panel assembly is to be secured to a transmission tower, bracket 69 may be affixed directly onto the tubing thereof.

The present invention relates to a panel antenna. More particularly, but not exclusively, the present invention relates to a panel antenna having both mechanical and electrical means for tilting the beam of the antenna. The antenna of the present invention is considered to be particularly suitable for use in cellular communication systems.

To the present time tilting of the beam of an antenna used in a cellular communication system has been achieved by mounting the panel antenna at an angle to a supporting structure. Where panel antennas are to be affixed to sides of buildings it is preferable that the panel antennas conform as closely as possible with the sides of the buildings for aesthetic reasons and to avoid exposing too great a surface area to the wind. Where conventional mounting arrangements are used a panel may be tilted by as much as 15° with respect to a building, which is unsightly, poses mounting difficulties and exposes the panel to the full impact of the wind. Likewise with panel antennas mounted on towers it is more asthetically pleasing, and the antennas are easier to mount and adjust, if they are mounted perpendicularly.

Another method of downwardly tilting the beam of a panel antenna is to electronically phase shift the signal received by or transmitted from each radiating element of a panel antenna by an amount corresponding with the desired degree of beam tilt. As the amount of beam tilt required

for each site varies (depending upon the height of the base-station etc) this would require the use of variable phase shifting elements, which would be expensive.

It is an object of the present invention to provide a panel antenna allowing customer adjustable beam down tilt which is relatively cheap and simple, whilst being easily mounted and aesthetically pleasing, or to at least provide the public with a useful choice.

Further aspects of this invention will become apparent from the following description.

According to the invention there is provided a panel antenna comprising:

a panel antenna comprising a plurality of spaced apart radiating elements mounted above a ground plane, said radiating elements being connected to a main feed line by a feed network, a first radiating element or group of radiating elements being connected to the main feed line via a first feed line, electrical beam tilting means comprising a delay line of a length selected from a pluarlity of lengths inserted in the electrical path of said first feed line to tilt the beam of the antenna by a desired amount with respect to the normal to the ground plane.

In a preferred embodiment the ground plane of the antenna can be tilted with respect to a housing.

Further aspects of this invention, which should be considered in all its novel aspects, will become apparent

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from the following description given by way of example of possible embodiments thereof and in which references made to the accompanying drawings wherein;

Figure 1:	shows 4 dipole pairs of a panel antenna mounted on a panel.
Figure 2:	shows one of the dipole pairs in detail.
Figure 3:	shows in detail the connection of the feed line to one of the dipole pairs shown in figure 2.
Figures 4a, 4b and 4c:	show the vertical (E-plane) radiation patterns for 0°, 5° and 10° for a 4 dipole pair antenna.
Figures 4d and 5d:	show electrical diagrams of possible configurations for a panel antenna having 4 radiating elements.
Figures 4e and 5e:	show electrical diagrams of possible configurations for a panel antenna having 8 radiating elements.
Figure 5a:	shows a matching section for matching the panel antenna to a feed line.

Figure 6:	shows a possible housing and tilt mechanism for the panel antenna.
Figure 7:	shows the back panel of the assembly shown in figure 6.
Figure 7a:	shows a cover which may be used to cover the assembly shown in figure 6.
Figure 8:	shows the tilting mechanism of figure 6 in greater detail.
Figure 9:	shows an alternative tilting mechanism.
Figure 10:	shows the tilting mechanism of figure 9 as seen through the aperture in the back panel.
Figure 11:	shows an alternative construction of the mechanism shown in figure 9.
Figure 12:	shows the central hinge of the mechanism shown in figure 11.
Figures 13 and 14:	show a wall mounting bracket for use in securing the panel antenna.

235010

<u>Figure 15</u>: shows a means of attaching the panel antenna to the wall mounting bracket.

<u>Figure 16</u>: shows a wide beam panel antenna embodiment.

<u>Figures 17a-e</u>: show various possible panel antenna configurations.

<u>Figures 17f-g</u>: show the horizontal (H-plane) radiation patterns for the configurations shown in figures 17b and d.

<u>Figure 18</u>: shows the single row dipole array panel driver of figure 16.

<u>Figure 19a</u>: shows a dipole of the array shown in figure 18.

<u>Figure 19b</u>: shows a side view of the dipole shown in figure 19a.

<u>Figure 19c</u>: shows an alternative dipole configuration.

<u>Figure 20</u>: shows a dipole element of the dipole shown in figures 19a and b.

<u>Figures 21 to 23</u>: show an alternative mechanical down-tilt mechanism.

The present invention relates to a panel antenna designed to operate over a wide band width (eg: 820 - 960 MHz) with constant beam tilt wherein the angle of beam tilt is adjustable by the customer on site.

Referring now to figure 1 the feed lines and radiating elements of a four dipole pair panel antenna having a beam width of about 60°are shown. In this case the radiating elements consist of four pairs of centre fed dipoles 1, 2, 3 and 4 mounted to panel 5 which forms the electrical ground plane. Panel 5 is tray shaped and preferably formed of aluminium. Preferably panel 5 is about 3.41L high by about 0.94L wide having side walls about 0.315L high (where L is the wavelength at the operating frequency). The dipoles in each pair are arranged in parallel and separated by L/2 so that in conjunction with the ground plane 5 they provide an H field beam of 60°. The dipole pairs 1, 2, 3 and 4 are preferably formed of brass and insulated from panel 5 by an insulating layer (such as a double sided foam tape) to avoid corrosion.

An radio frequency signal supplied at connector 6 is fed by main feed line 6a to power divider 7 which divides the

Thus the radiation pattern must be optimised for a selected angle of down tilt and performance compromised for the other angles.

In one embodiment four dipole pairs were used and the best compromise was achieved for a down tilt of 10°. If d = 0.8L then S = 50° (thus elements 31 and 32 in figure 4d are phase delays of 50°). The radiation pattern obtained when the phase shift between delay 29 and delay 30 (delay 29 - delay 30) is 0°, 50.2° and 100° is shown in figures 4a, 4b and 4c respectively. It is seen in figure 4c that the upper lobes are minimised when the angle of down tilt is 10°.

Referring now to figure 5d, this circuit incorporates power dividers 33, 34, 35, 36, 37 and 38. These power dividers may have differing characteristics to give different power division. This may enable better control of the sidelobes.

Embodiments incorporating 8 dipole pairs are shown in figures 4e and 5e.

It is to be appreciated that other numbers of radiating elements may be used in other embodiments. Embodiments incorporating 2, 4, 8 or 16 ... radiating elements are preferred.

The previous description relates to a 60° H-plane beamwidth embodiment (the beamwidth being measured at the half power

points). The beamwidth in this embodiment is determined by the length, width and height of the tray 5. These dimensions also affect the unwanted power distribution outside the main beam.

In other embodiments a wider beamwidth over the range 60°-120°, or even to 180° may be required. In such wide beamwidth embodiments a single row of dipoles is preferred to achieve the desired beam. In figure 16 a single row of dipoles 102 are shown mounted upon conduit 101. In this form of construction the conduit 101 can act as the first level of a "compound ground plane". Further, the conduit 101 can provide a channel to carry the feed lines.

Figure 17a shows the embodiment of figure 1 driven by dipole pairs. Figures 17b-e show embodiments incorporating the panel driver shown in figure 18. In figure 17b the panel driver 103 is seen to be on the same level as ground plane 104. In figure 17c the conduit of panel driver 105 forms the first level of a ground plane with ground plane 106 forming the second level. This configuration gives a similar effect to tilting the ground plane back slightly.

Figure 17d shows an embodiment in which ground planes 108 are tilted backwardly from the direction of beam propagation. This produces greater beamwidth. In the embodiment shown in figure 17e ground planes 110 project backwardly from the top edges of the conduit of panel driver 109.

The walls 104a, 106a, 108a and 110a may have positive, negative or equal values. Figures 17b and c show positive values. Figures 17d and e show negative values.
By inclining the back plane as shown in figure 17d and 17e, a front to back ratio better than 20dB can be achieved. Referring to figure 17f, a radiation plot for a panel antenna of the form shown in figure 17b is shown for a beamwidth of 105.6°. The height of the radiating element above the ground plane is .223L and the width of the ground plane is .564L.

Figure 17g shows a radiation plot for a beam width of 105.33° for the panel antenna shown in figure 17e. It will be seen that the back of the radiation pattern (ie: on the left hand side) does not project beyond the innermost circle as did the radiation pattern in figure 17f. The result is a front to back ratio of 22.66dB. The panel antenna width is .944L and the height of the dipole above the ground plane is .25L. The included angle is 173.2° and the negative sidewalls of 0.18L length. The negative sidewalls further increase the front-to-back ratio and also provide a mounting for a swivel mechanism.

Referring now to figure 19a and 19b, the preferred dipole for the panel driver shown in figure 18 is shown. This dipole is suitable for use in wide beam width embodiments. Dipole elements 111a and b are supported by balun 112 and

fed by cable 113. The outer conductor of the coaxial cable 113 is solder bonded at 116. The inner conductor extends to radiating element 111a and is soldered thereto at 114. The outer conductor of the coaxial cable is also solder bonded at point 117. Flange 115 enables the attachment of the dipole to a channel as shown in figure 18.

In figure 19c an alternative embodiment is shown in which the adjacent ends of dipole elements 111a and 111b are upturned and downturned respectively so that the ends may be overlapping whilst dipole elements 111a and 111b are at the same level.

Figure 20 is a planar view of one of the dipole elements 111a/b shown in figures 19a-c. The dimensions of the dipole elements are preferably approximately as follows:
119 - 0.21L
120 - 0.053L
121 - 0.184L
122 - 0.068L.
These flat dipole elements are preferred for wider beam width panels (60°-180°) as they are cheaper to manufacture. The spread of radiation resistance and electrical resistance is dependant upon the shape of the dipole element. It has been found that the shape of dipole element shown in figure 20 produces a reactance spread which is within the 14dB return loss limit.

Mechanisms for mechanically tilting the beam of the panel antenna will now be described. It is an advantage of the present invention that the ground plane of the panel antenna can be fitted with respect to a housing to allow easy adjustment of mechanical down tilt.

Referring now to figure 6 a first mechanism to provide mechanical down-tilt of the ground plane is shown. The equivalent of the panel shown in figure 1 is seen housed within housing 40 in figure 6. Panel 5 is rotatable with respect to housing 40 about pivot centre 41 near the centre of gravity. Housing 40 may be mounted to a building or tower or vertical pipe etc by means of brackets 42 etc.

By allowing rotation of panel 5 with respect to housing 40 a certain degree of mechanical down tilting of the antenna beam may be achieved. In one embodiment, with reference to figures 7 and 8 as well, an aperture 43 may be provided in the back of housing 40 through which a person can grasp handle 44 and by pushing or pulling rotate panel antenna 5 with respect of housing 40.

A pair of lugs 45 and 46 are attached to housing 40 and panel 5 respectively. Lug 46 has an arcuate slot 47 therein which corresponds with the arc of a circle about point 41. Lug 45 has a slot 48 therein in the vertical direction. A bolt 49 passes through the slots 47 and 48 so as to restrict rotation of panel antenna 5 with respect

to housing 40 to the movement allowed between the ends of slot 47. Complimentary brackets 45 and 46 may be provided on the other side of the housing and ground plane. A tube may extend between the lugs at either side, through which passes a rod with a head at one end and thread at the other. A nut can be fastened to the threaded end to clamp together the brackets 45 and 46 and prevent rotation of the ground plane with respect to the housing.

In use an operator may grasp handle 44 and rotate panel antenna 5 with respect to housing 40 until bolt 49 is adjacent the required amount of down tilt indicated on indicator 50. When in the correct position the operator will then fasten a nut (not shown) to bolt 49 to secure the assembly firmly in place and prevent further rotation of panel 5. A spirit level 51 may also be provided so that an operator may check to see that the assembly is level when initially installed.

Connectors 29a and 29b may be positioned so as to be easily accessible through aperture 43. In this way lengths of cable may be easily interchanged to give different degrees of down tilt.

Thus, the panel antenna of the present invention provides for a combination of customer adjustable mechanical down tilt and customer adjustable electrical down tilt (by varying the length of cable 29).

Different lengths of cable 29 may be provided to give incrementally greater amounts of electrical down tilt, with mechanical down tilt equal to the incremental steps being available. In this way steps of 5° electrical down tilt may be provided (ie 0°, 5°, 10° cable delays) and fine tuning may be achieved within the range of 5° mechanical down tilt. A total of 15° down tilt may be achieved in this embodiment.

Anywhere from 2° to 15° mechanical down tilt may be provided depending upon the particular configuration. For 8 dipole pairs 2.5° mechanical down tilt may be appropriate, whereas 10° mechanical down tilt may be appropriate for 2 dipole pairs.

For some applications only electrical down tilt may be required and panel 5 may be directly mounted without the need for housing 40 or the mechanical down tilt mechanism. If only electrical down tilt is employed then a greater range of cable lengths 43 may be provided to allow finer control of the amount of down tilt.

According to another embodiment a plurality of switches may be provided on the back of panel 5 which enable the lengths of a plurality of feed lines to be adjusted. If the length of a number of feed lines can be adjusted then a better radiation pattern can be achieved for the non-optimum angles of down tilt. This approach is however more expensive. In another embodiment the feed line lengths may be adjusted remotely using a solenoid rotary switch etc.

Figure 7a shows a cover suitable for covering the whole antenna assembly. This may be formed of rovel (styrene acrylonitrite copolymer) which is a material having low radio frequency loss and high resistance to ultraviolet radiation. Cover 7a protects the front and sides from the elements with access port 43 being closed by a suitable weather-proof portal cover.

Referring now to figure 9 an alternate mechanism for adjusting mechanical down tilt is shown. A bracket 52 is secured to the back of panel 5 with members 53 and 54 being pivotally connected to each other and box 40 and panel 5 respectively. Adjustment means 55 is connected between the point of connection of members 53 and 54 and bracket 52.

The length of adjustment means 55 may be adjusted by rotating turn buckle 56 with respect to threaded shaft 57. As the length of adjustment means 55 is increased members 53 and 54 are straightened which tilts panel 5 further forward with respect to box 40. A lock nut 58 is provided to secure the mechanism when the desired degree of down tilt is achieved. A spring 59 may be connected between bracket 52 and the intersection of members 53 and 54. This spring may be provided with an indicator 60 which moves along a graduated scale 61 to indicate the degree of down tilt (as best seen in figure 10).

This mechanism has the advantage that fine adjustment may easily be made by an operator through port 43 and the operator need have no special tools. Panel 5 will preferably be electrically isolated from box 40 so as to prevent corrosion and members 53 and 54 will preferably be formed of an insulating material.

Referring now to figure 11 an embodiment is shown in which members 53 and 54 shown in figure 9 are formed by three hinges 62, 63 and 64. This configuration has the advantage that the hinges have very little movement about their joints so the assembly will be securely fastened in place. The hinges 62, 63 and 64 will preferably be formed of nylon or plastic material to isolate box 5 from box 4. The hinge 63 shown in figure 12 will preferably have a notch 65 therein to allow attachment of the adjustment means 55.

Referring now to figures 21 to 23 an alternative tilting mechanism is shown. Ground plane 202 has a bracket 205 secured thereto with a threaded rod 206 extending therefrom. Mounting plate 201 has a bracket 204 secured thereto with a threaded rod 207 extending therefrom. Threads 206 and 207 are of opposite types (ie: one is a left hand thread and one is a right hand thread). Turnbuckle 209 has a central nut having right handed and left handed threads in either end thereof to engage with threaded rods 206 and 207. When turnbuckle 209 is rotated

in a first direction ground plane 202 is forced away from mounting plate 201. When turnbuckle 209 is rotated in the other direction ground plane 202 is drawn towards mounting plane 201. Accordingly tilting of ground plane 202 with respect to mounting plate 201 can be effected with this mechanism.

Turnbuckle 209 can be connected to suitable motorised driving means to allow the remote mechanical tilting of the ground plane. It may be appropriate to include a speed reducing unit to achieve the desired speed of operation. It may also be appropriate to include means to sense the degree of mechanical down-tilt.

Where the degree of mechanical down tilt is to be adjusted remotely the tilting mechanism may be driven by an electric motor through a suitable assembly.

Referring now to figure 13 a mounting bracket for securing the panel antenna assembly to a wall is shown. The bracket is seen to comprise a back plate 66, a horizontal plate 67, an angle support plate 68 and a cylindrical pin 69. Back plate 68 may be affixed to a wall by any suitable means such as bolting. A panel antenna assembly may be mounted onto two such vertically disposed support brackets using two mounting brackets 69 fastened together by bolts 70 and

nuts 71. This assembly has the advantage that the panel antenna assembly is rotatable with respect to the brackets through 40° in either direction. This assists in adjustment of the antenna down tilt after installation as upon loosening of nuts 71 the panel antenna assembly may be rotated to enable access through the rear thereof.

Where the panel assembly is to be secured to a transmission tower, bracket 69 may be affixed directly onto the tubing thereof.

The present invention thus provides a cheap and relatively simple panel antenna having customer adjustable electrical and mechanical down tilt which is particularly suitable for application in cellular telephone networks.

Where in the aforegoing description reference has been made to integers having known equivalents then such equivalents are herein incorporated as if individually set forth.

Although this invention has been described by way of example and with reference to possible embodiments thereof it is to be appreciated that improvements and modifications may be made thereto without departing from the scope or spirit of the present invention. The claims form part of the disclosure of this specification.

WHAT WE CLAIM IS:

1. A panel antenna comprising a plurality of spaced apart radiating elements mounted above a ground plane, said radiating elements being connected to a main feed line by a feed network, a first radiating element or group of radiating elements being connected to the main feed line via a first feed line, electrical beam tilting means comprising a delay line of a length selected from a plurality of lengths inserted in the electrical path of said first feed line to tilt the beam of the antenna by a desired amount with respect to the normal to the ground plane.

2. A panel antenna as claimed in claim 1 wherein said electrical beam tilting means comprises a plurality of delay lines of different lengths, a selected one of which may be inserted in the electrical path of said first feed line.

3. A panel antenna as claimed in claim 2 wherein said electrical beam tilting means includes a switch which can selectively insert a selected one of said delay lines in the electrical path of said feed line.

4. A panel antenna as claimed in claim 1 or claim 2 wherein each delay line is provided with connectors at each end thereof engagable with corresponding connectors in said first feed line.

5. A panel antenna as claimed in any one of the preceding claims wherein the panel antenna is mounted within a housing

235010

and can be tilted with respect of the housing by a mechanical tilt means to allow mechanical tilting.

6. A panel antenna as claimed in claim 5 wherein said mechanical tilt means has a maximum mechanical tilting angle and the delay lines are of lengths which produce angles of electrical beam tilting approximately equal to integer multiples of the maximum mechanical tilting angle.

7. A panel antenna as claimed in claim 5 or claim 6 wherein the mechanical tilt means allows tilting of a value within the range of 2° to 15°.

8. A panel antenna as claimed in any one of claims 2 to 7 wherein the delay lines are of lengths which produce approximate integer multiples of electrical beam tilting of 5°.

9. A panel antenna as claimed in any one of the preceding claims wherein delay lines are inserted in a number of feed lines of said feed network.

10. A panel antenna as claimed in any one of the preceding claims wherein the radiating elements of the panel antenna are dipoles.

11. A panel antenna as claimed in any one of the preceding claims having four or more radiating elements.

12. A panel antenna as claimed in any one of the preceding claims wherein a matching section is provided in the main feed line to match the antenna impedance to that of the line feeding the antenna, wherein the matching section consists of an outer tubular conductor, an inner conductor and a tubular dielectric section between the outer tubular conductor and inner conductor for part of the length of the outer tubular conductor.

13. A panel antenna as claimed in any one of the preceding claims wherein unequal power dividers are inserted in feed lines to the radiating elements to decrease the side lobes of the panel antenna beam.

14. A panel antenna as claimed in claim 3 or claim 4 wherein the ground plane is tiltable about a pivot centre near its centre of gravity, said ground plane having secured on either side thereof brackets having arcuate slots therein, said housing having brackets secured thereto with apertures adjacent said arcuate slots, a hollow tube extending between said pairs of brackets having therein a rod passing through said arcuate slots and apertures and having a head at one end thereof, the other end of said rod being threaded and fitted with a nut, wherein, upon fastening of said nut, both sides of said ground plane are secured against rotation with respect to said housing.

15. A panel antenna as claimed is any one of claims 5 to 7 wherein the mechanical tilt means comprises a first threaded rod connected to said housing, a second threaded rod connected to said ground plane and a turnbuckle having threaded bores engaged with said first and second threaded rods, one threaded rod having a right hand thread and the other having a left hand thread so that rotation of said turnbuckle tilts the ground plane with respect to the housing.

16. A panel antenna comprising:
   (a) a plurality of spaced apart dipoles, each mounted above a ground plane, said dipoles and said ground plane being disposed within a housing;
   (b) a means to electrically tilt the transmitted beam by varying the phase of a signal input to a first group of at least one of said dipoles in relation to the phase of said signal input to a second group of the other said dipoles wherein said electrical tilt means comprises a plurality of delay lines of different lengths that can be selectively inserted in the electrical path of said signal input to one of said groups of said dipoles to cause said varying of the phase of the signal input to said first group of dipoles, and

   (c) a means to mechanically tilt said ground plane with respect to said housing.

235010

17. A panel antenna substantially as herein described with reference to any one of the embodiments shown in the accompanying drawings.

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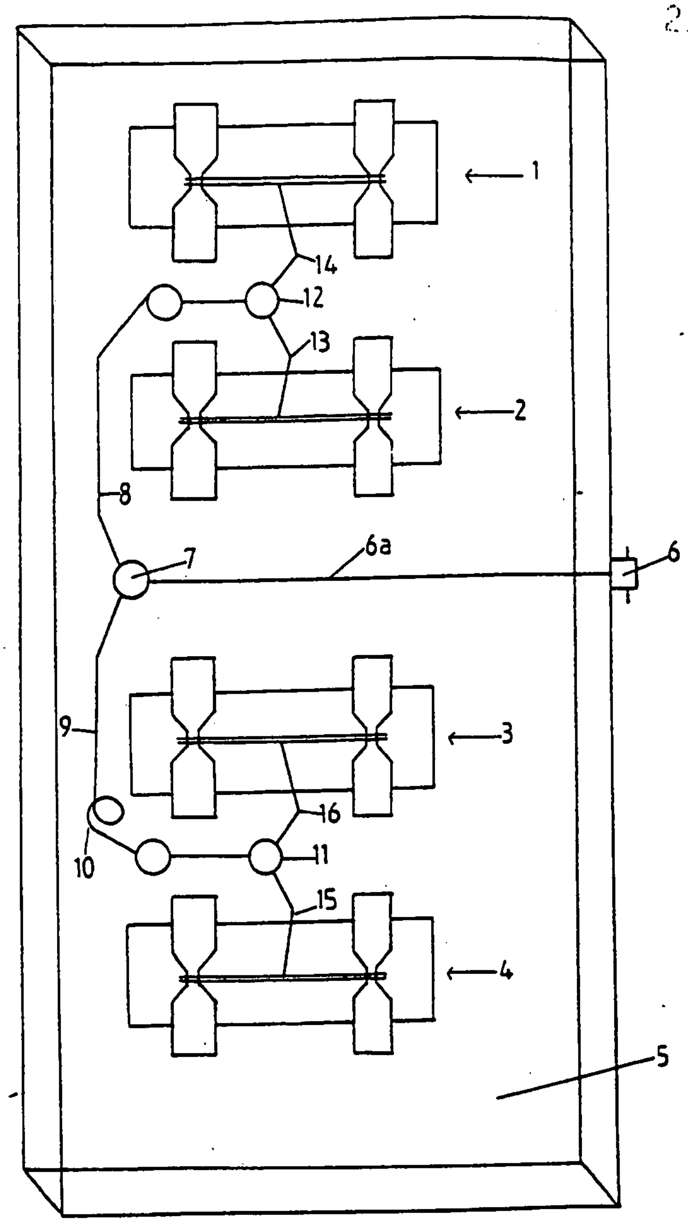

FIG.1

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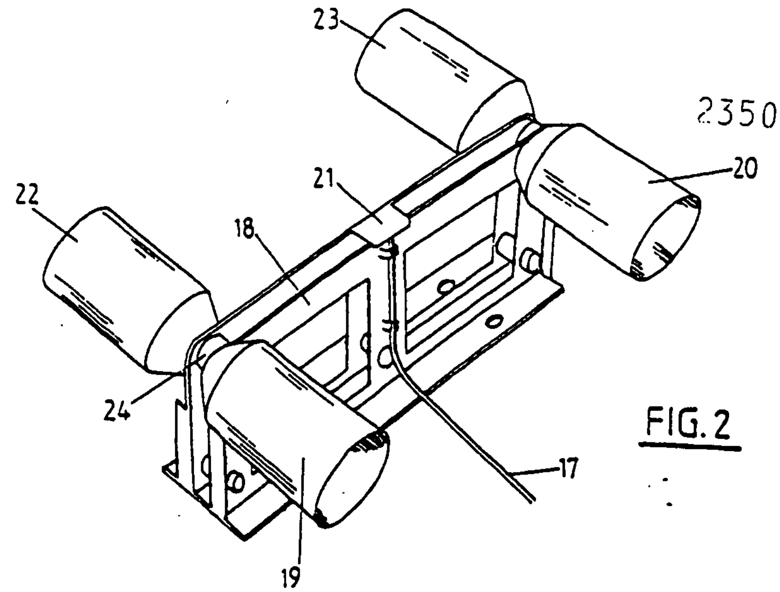

FIG. 2

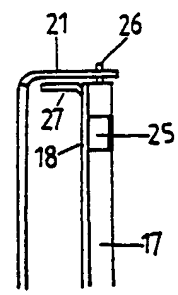

FIG. 3

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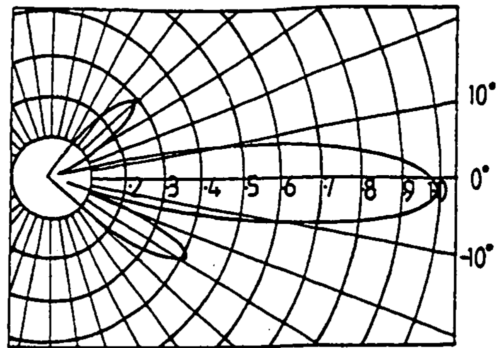
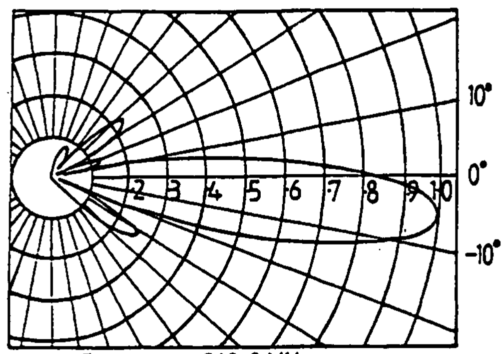
FIG.4a



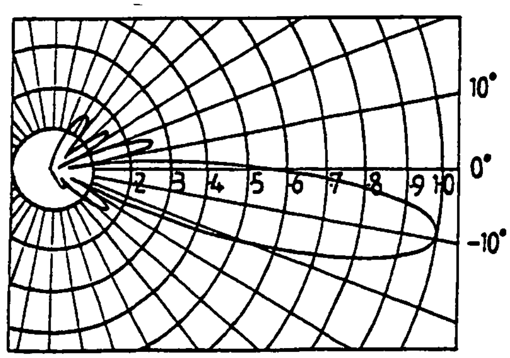
Frequency = 960·0 MHz

FIG.4b



Frequency = 960·0 MHz

FIG.4c



Frequency = 960·0 MHz

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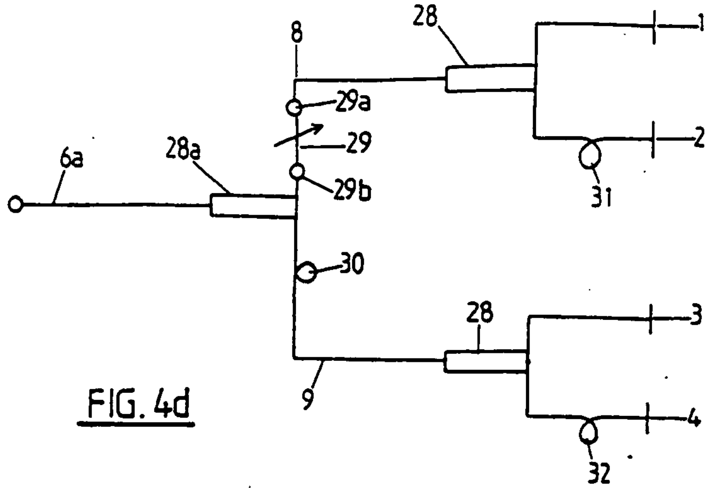

FIG. 4d

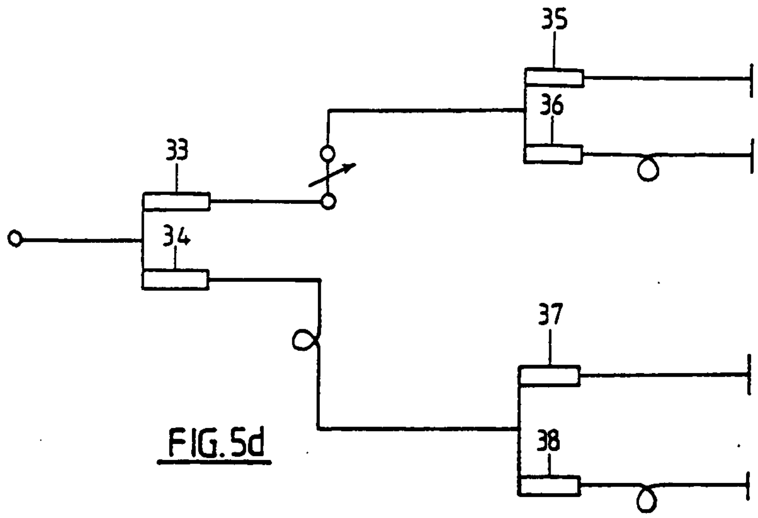

FIG. 5d

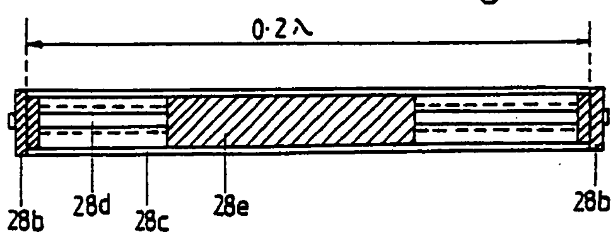

FIG. 5a

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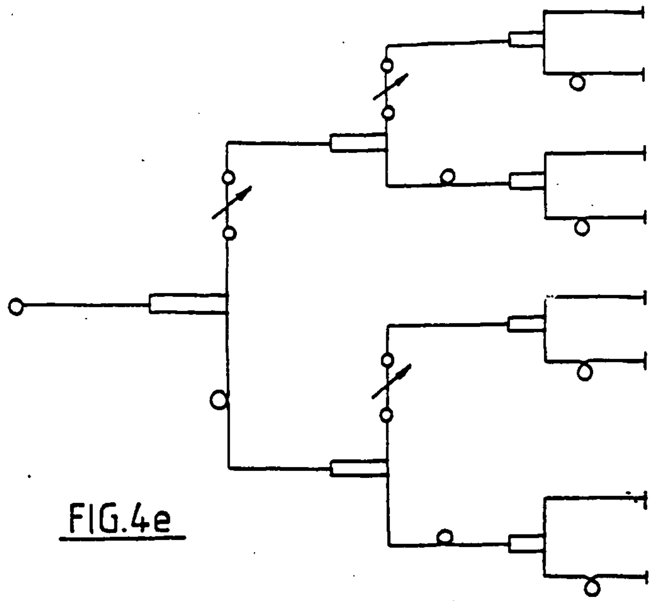

FIG.4e

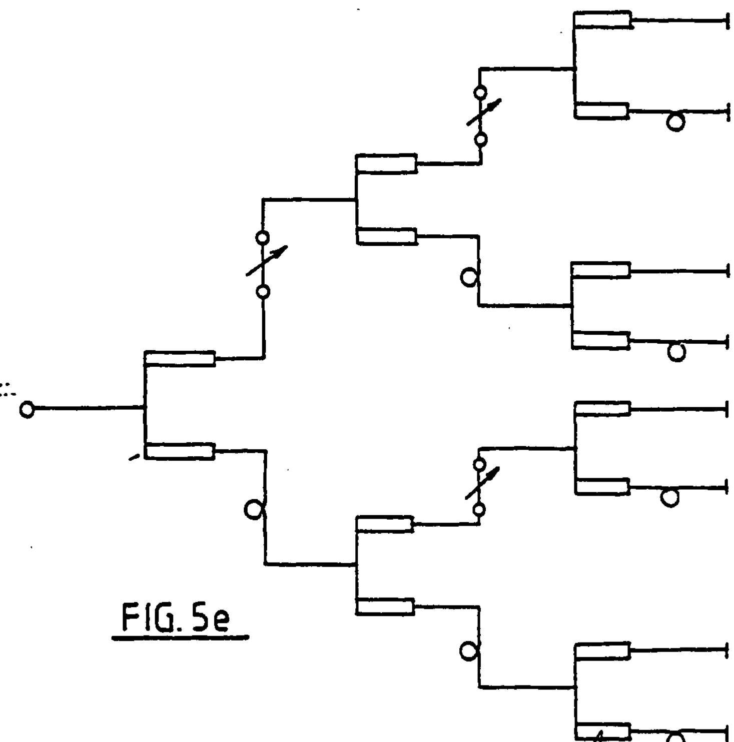

FIG. 5e

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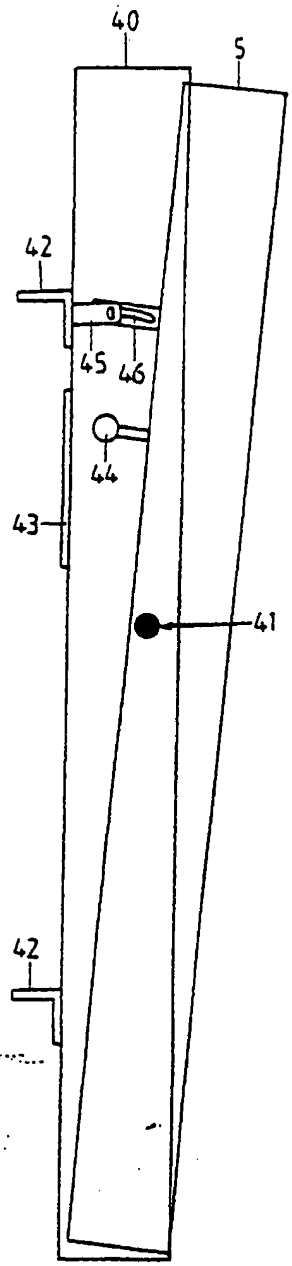

FIG.6

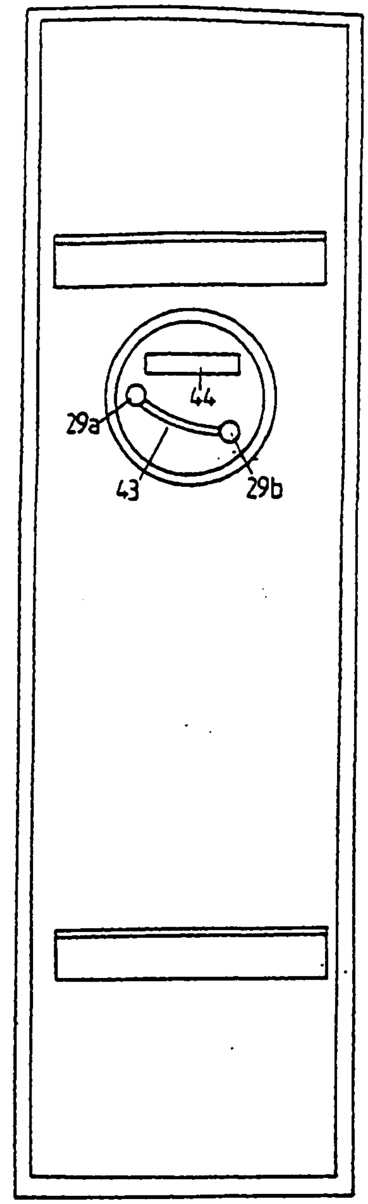

FIG. 7

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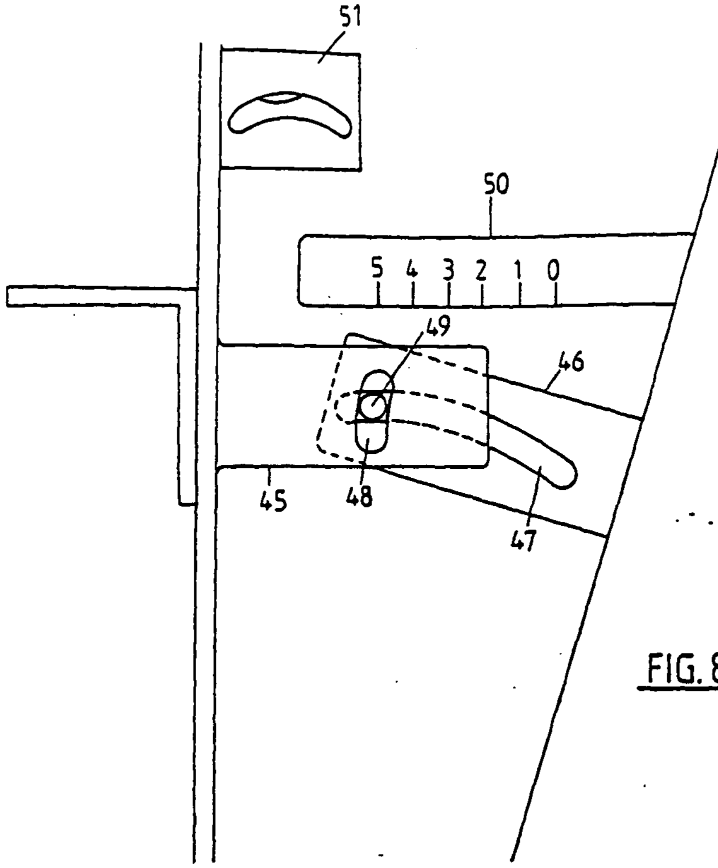

FIG. 8

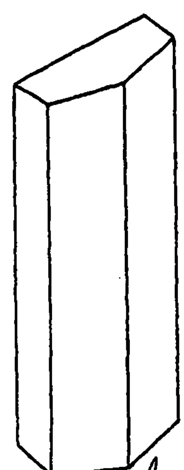

FIG. 7a

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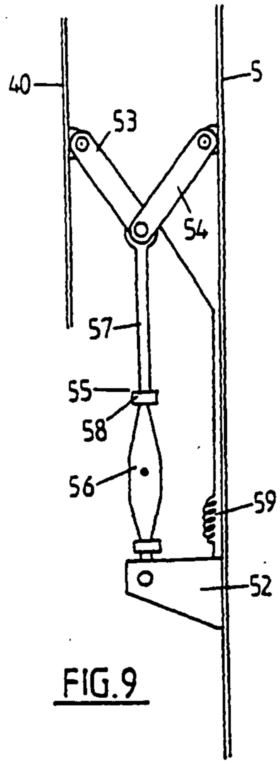

FIG.9

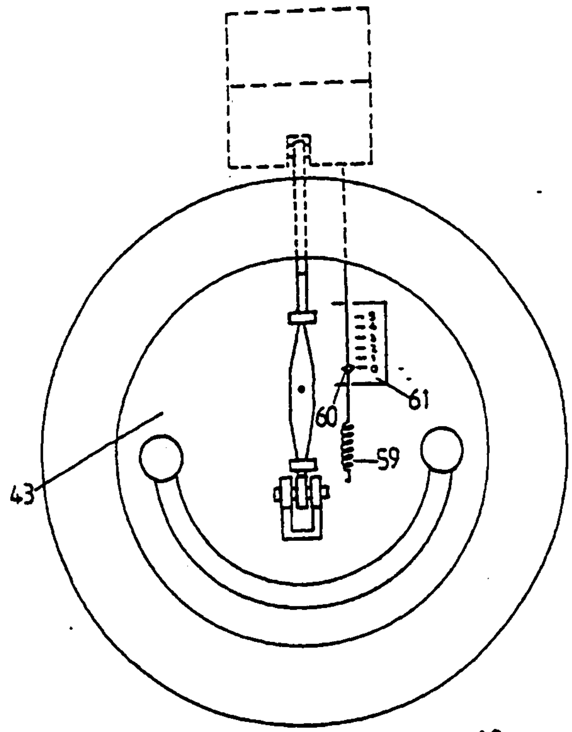

FIG. 10

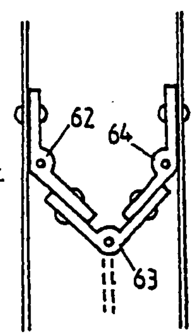

FIG. 11

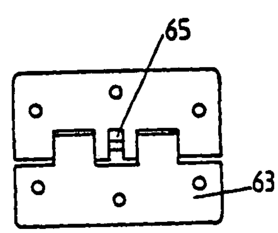

FIG. 12

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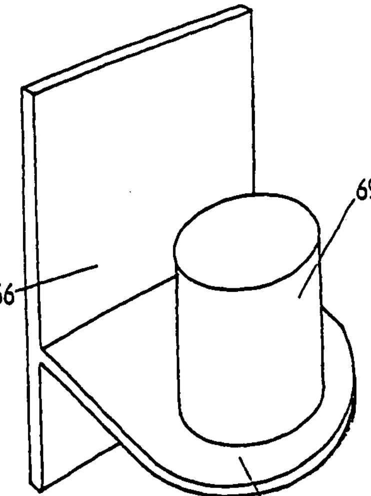

FIG. 13

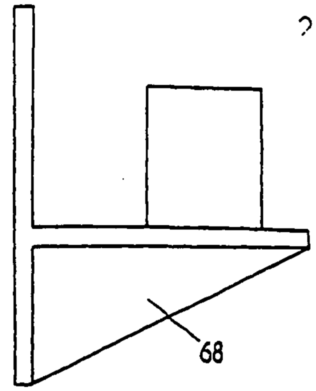

FIG. 14

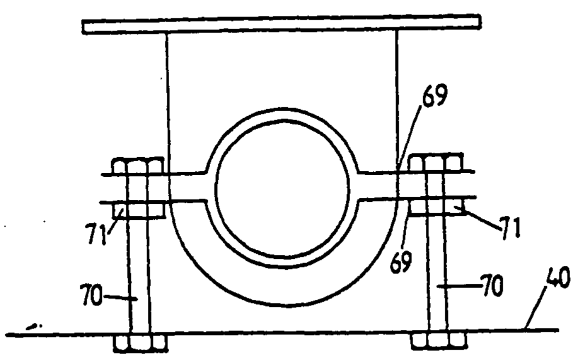

FIG. 15

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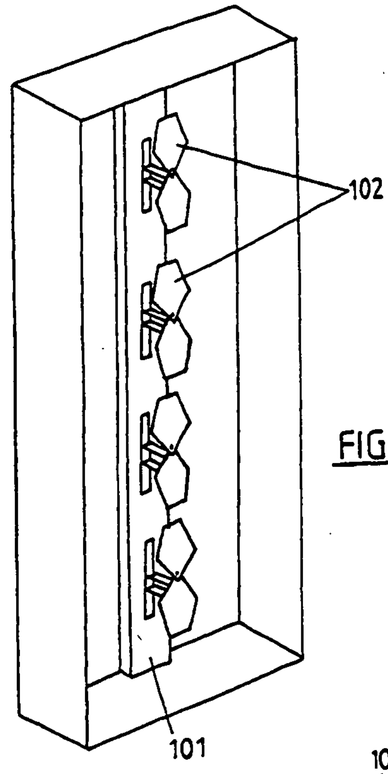

FIG.16

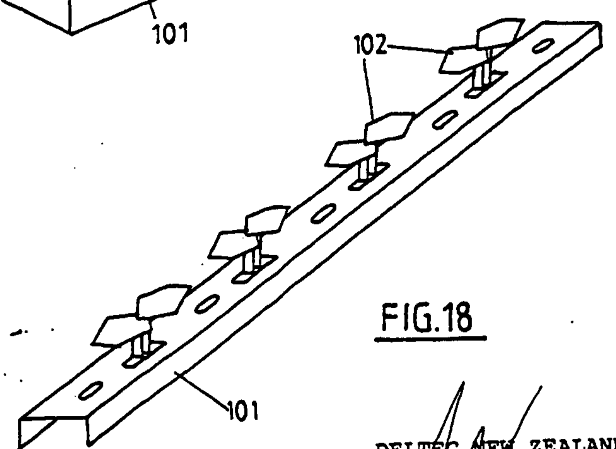

FIG.18

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FIG.17a

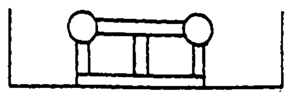


FIG.17b

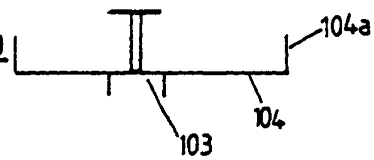


FIG.17c

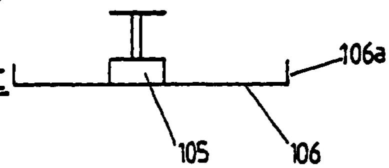


FIG.17d

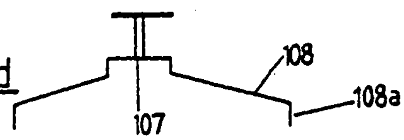
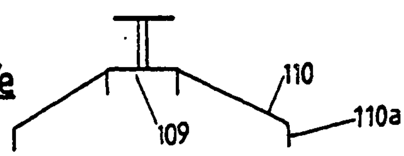


FIG.17e



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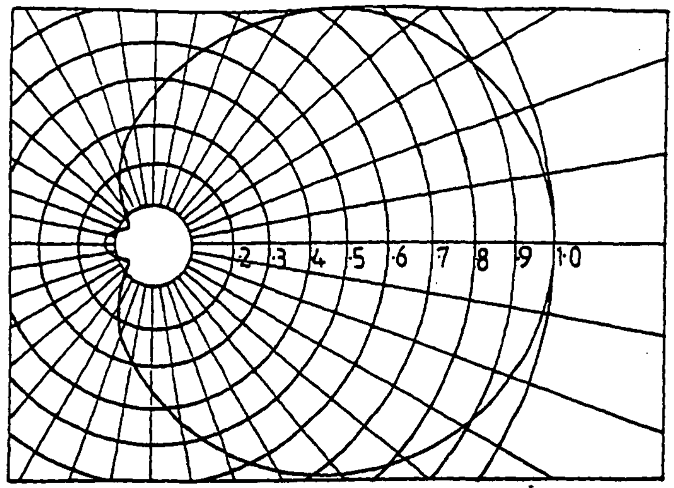
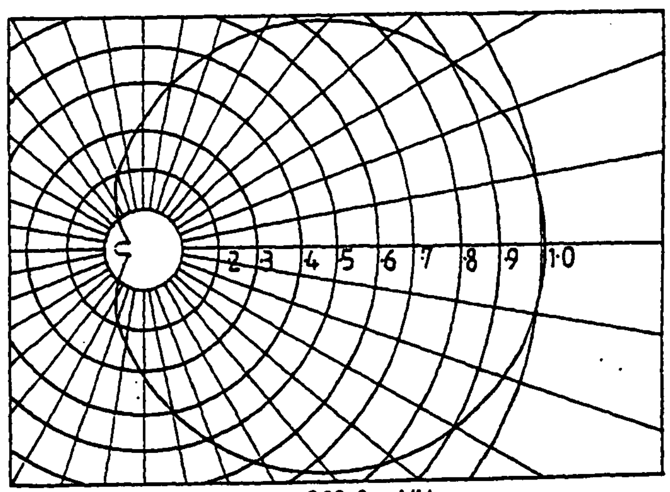


Frequency = 980·0 MHz

FIG. 17f



Frequency = 890·0 MHz

FIG. 17g

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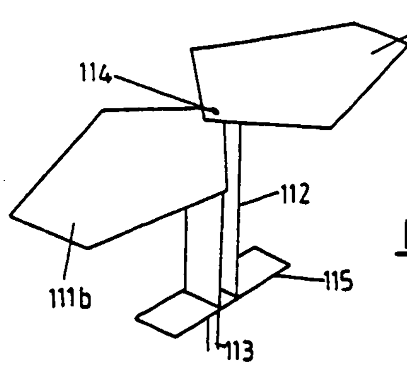

FIG. 19a

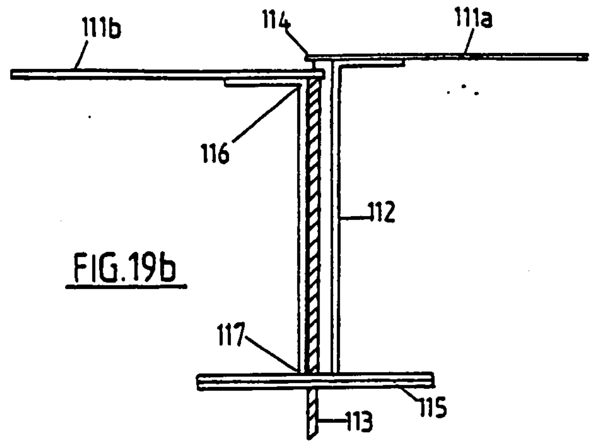

FIG.19b

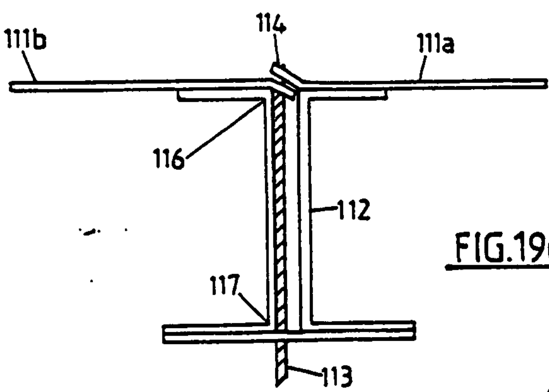

FIG.19c

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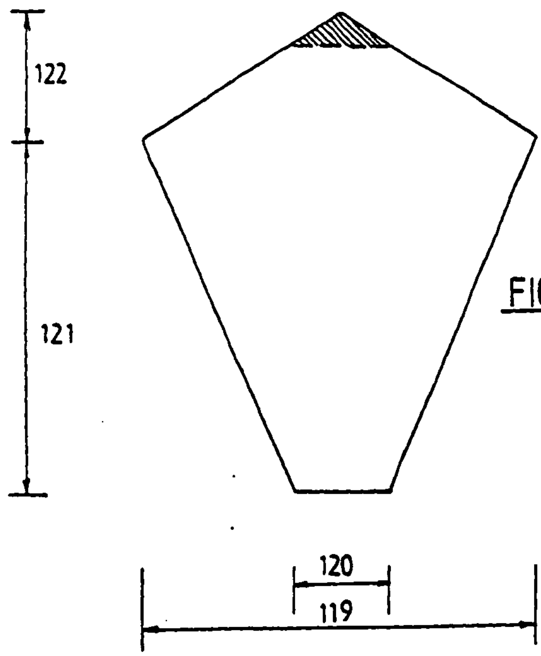

FIG. 20

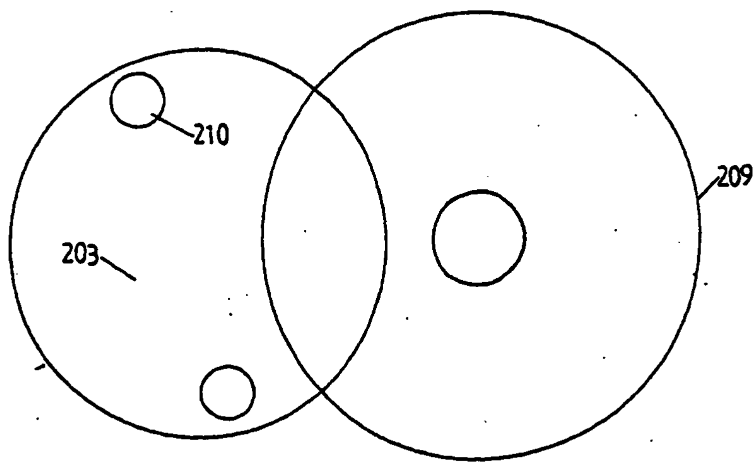

FIG. 22

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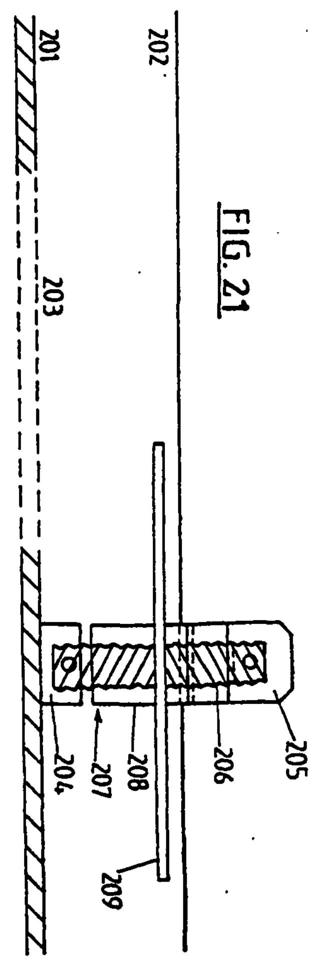

FIG. 21

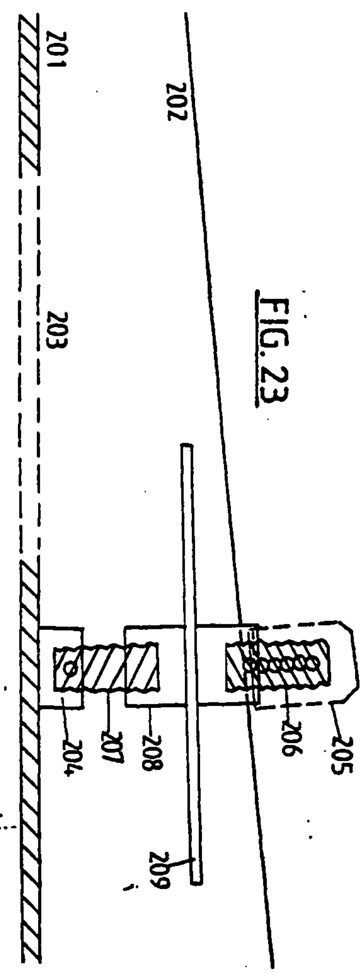

FIG. 23

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